2012-02-01

Next Meltdown? Responding to a Nuclear Accident in the Developing World

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Homeland Security Affairs (February 2012), v.8, article 2

The Next Meltdown?
Responding to a Nuclear Accident in theDeveloping World

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ABSTRACT

As the twenty-first century begins, an increasing number of developing nations are aggressively pursuing the use of nuclear power as a source of electricity. Much attention within the international security community has been placed on the growth of reactors within the context of nuclear weapons development and nuclear terrorism. A major accident involving a nuclear reactor or stored nuclear waste may be a more likely possibility, albeit one that has received considerably less attention in terms of disaster planning and response. In the aftermath of such a disaster, intervention by the United States, and other Western nations, may be warranted. In the context of homeland security operations in such a scenario, major challenges will revolve around efforts to detect and deter the importation of goods contaminated with radionuclides, and screening and processing of refugees and immigrants from nations and territories affected by the nuclear accident.

INTRODUCTION

The expansion of nuclear power into developing nations raises the likelihood of a disaster similar to that of Fukushima, Japan, taking place in a state that is profoundly ill equipped to deal with the consequences of fallout on a large section of its habitable territory. In such a scenario, the possibility that appreciable, even hazardous, amounts of radioactive contamination would be present on travelers and goods arriving in the United States is not far-fetched. Depending (of course) on the severity and extent of such exposure, Department of Homeland Security (DHS) operations may be of considerable importance in promoting the public health of travelers and the economic stability of importers and other individuals/companies involved with international trade.

While securing nuclear materials in an effort to stymie clandestine efforts to fabricate explosives is a worthy goal, too little attention has been placed on the potentially disastrous consequences that would ensue from an accident resulting from a legitimate use of nuclear power. What would happen if tomorrow an accident of the magnitude of Fukushima or Chernobyl were to occur in Jordan? Or Bangladesh? Or Vietnam? Would the affected country be capable of addressing the accident? What DHS operations would need to be expanded or enhanced in order to deal with the consequences of a major nuclear disaster in a developing nation? As the Fukushima accident has indicated, these questions are in need of consideration.

THE FUKUSHIMA NUCLEAR CRISIS

As this is written, in January 2012, the most worrisome aspects of the crisis created by the earthquake and tsunami- related damage to the six reactors at the Fukushima Daiichi I nuclear power plant in Fukushima, Japan, appear to have been successfully managed.

The crisis, which began on March 11, 2011, was the worst associated with a nuclear power operation since the Chernobyl disaster of April 1986. The sequence of events, as is best understood, started with the earthquake, which resulted in the automatic shutdown of the three reactors, Nos. 1, 2, and 3 (Nos. 4, 5, and 6 were shut down for maintenance), in operation at the Daiichi complex. The earthquake disrupted electrical power to the plant; as was designed in the event of such an emergency, the backup electrical system provided power to run the water-based cooling systems for the reactors. However, the forty-five-foot tsunami wave reaching shore forty minutes after the earthquake brought all emergency generators offline. With no way to circulate water through the reactor pressure vessels (RPV) housing the reactor cores, the temperatures of the cores increased, leading to "meltdowns" of the fuel assemblies in Reactors 1, 2 and 3.[1]

The high temperatures converted the water in the Reactor 1 RPV, and associated piping, to hydrogen gas. It is thought that the escape/venting of hydrogen gasses into the primary containment vessel (PCV), the structure surrounding the RPV, led to an explosion on March 12 that destroyed a large portion of the Reactor 1 building. It is also thought that hydrogen gas generated in Reactor 3 not only caused a smaller explosion within its RPV, but also leaked to the adjacent building housing Reactor No. 4. This resulted in an explosion on March 15 that removed a portion of the roof of the Reactor 4 building, and collaterally damaged the Reactor 3 building.[2]

Figure 1. Reactor No. 4 (foreground) and Reactor No. 3 (background) at the Fukushima Daiichi nuclear power installation, March 16, 2011 (photograph courtesy of Kyodo News/AP)

There was considerable fear early on in the disaster regarding the cooling ponds, which contain up to 1,400 tons of water to a depth of thirty-nine feet and are located atop each of the six reactor buildings. These ponds are used to store anywhere from fifty to 151 tons of spent fuel rods containing uranium pellets within a zirconium-alloy cladding. The March 15 explosion at the Reactor 4 building resulted in the creation of a leak, and a loss of water, from the cooling pond located atop the building. This raised the possibility that the heat from the pool's spent fuel rods would eventually "boil off" all remaining water from the pool, leaving the rods exposed to the air. This would increase their temperature, leading to their catching fire, followed by the strong likelihood of an explosion involving most (if not all) the fuel rods in the pool. This catastrophe was averted through improvised measures, including dumps of water from a helicopter, spraying water into the pond using fire truck water cannons, and, starting on March 18, the use of concrete pumping vehicles flown into Japan from the United States. Ultimately, the continuous deposition of nearly 1,100 square feet of seawater/fresh water into the pool on a daily basis prevented overheating of the fuel rods, and permitted the implementation of more permanent cooling systems in May.[3]

By June, 3,700 workers were laboring on cleanup and restoration efforts, which included pumping 500 metric tons of sweater into the facility daily, in order to maintain the cooling capacities for the three reactors and four spent fuel pools. Gradually, new systems were installed, or existing systems repaired, to recirculate coolant among the reactors and spent fuel pools.[4]

In October a covering structure 177 feet high was erected over the Reactor 1 building to contain further discharges of radioactive materials; it is intended to remain in place for at least two years. Similar coverings are planned for placement over Reactor 2 and Reactor 3 in 2012. On December 16, 2011, Prime Minister Yoshihiko Noda announced that the Fukushima plant was in "cold shutdown"; in other words, the temperatures in the damaged reactors had been reduced to below the boiling point of water. The long-term plans for remediation of the Fukushima Daiichi plant call for identification and repair of leaks or cracks in the primary containment vessels and reactor buildings, followed by the removal, and interment, of fuel from the damaged reactors. As well, the 90,000 tons of contaminated seawater and freshwater used to cool the reactors in the aftermath of the disaster will need to be stored on site until they can be decontaminated and released into the environment. The overall repair and remediation efforts at the Daiichi plant are estimated to take twenty-five years to complete.[5]

While the exact quantities never will be known, the Nuclear and Industrial Safety Agency of Japan (NISA) has estimated that 130 petabecquerels (PBq) of radioactive iodine (^{131}I) and 6.1 PBq of radioactive cesium (^{137}Cs) were released into the atmosphere due to the explosions.[6] This is approximately 5 to 6 percent of the amounts released by the Chernobyl disaster.[7]

Approximately 100,000 people, in evacuation zones extending up to forty kilometers (equivalent to twenty-five miles) from the reactor site, were evacuated or otherwise "displaced"; when, and if, they can return to their homes is unclear. The Japanese government has delineated a "contamination zone" of 930 square miles that will be targeted for comprehensive cleanup; such an operation will not be trivial. Based on measurements of ^{137}Cs in soil samples, one study has estimated that the region northwest of the plant has been contaminated with 1,000 kilobecquerels (KBq) per square meter. By way of comparison, in the aftermath of the Chernobyl accident, Soviet authorities permanently evacuated areas with approximately 1,500 kBq per square meter. Because the half-life of ^{137}Cs is thirty years, soil contamination and associated remediation efforts (such as the removal of topsoil from affected cropland) will have long-term impacts on the future of agriculture and food production in many areas of Japan.[8]

IMPLICATIONS FOR UNITED STATES HOMELAND SECURITY

If mainstream media coverage was any indicator, DHS operations in response to the Fukushima accident initially focused on screening airplane passengers (and cargo) arriving in the United States from Japan for the presence of radionuclides. Screening of passengers apparently began on March 17, 2011, with Secretary Janet Napolitano announcing the screening being performed "in an exercise of caution."[9] One passenger arriving at Los Angeles International Airport described uniformed personnel (i.e., US Customs and Border Protection officials, CBP) "[as] holding some sort of device and sweeping it over people as they walked by."[10]

With regard to cargo, in the port of Oakland, the CBP was screening incoming containers from Japan for the presence of radioactive contamination using truck-mounted devices as well as hand-held devices. The devices (radiation portal monitors, or RPM), installed as part of a collaborative effort by the DHS Domestic Nuclear Detection Office and CBP, are capable of detecting gamma and neutron emissions.[11] Not only were containers being scanned, but trucks exiting the shipyard with cargo also were required to pass through a scanning portal. Encouragingly, as of early April 2011, no incoming containers tested positive.[12]

With the discovery later in the Spring of 2011 that spinach and milk from producers located more than thirty miles from the Fukushima installation contained higher than normal amounts of ^{131}I, the Food and Drug Administration (FDA) banned imports of foods produced in the Fukushima region into the United States. In collaboration with the CBP, the FDA was investigating the use of the Automated Targeting System to identify and track non-food items, such as drugs and biologics, which also are imported from Japan and are under FDA regulation.[13]

The DHS also sponsored environmental and food monitoring studies related to the Fukushima accident; for example, a team of scientists from the University of California, Berkeley, collected rainwater in the San Francisco area during the interval of March 16-26 and detected radioisotopes of iodine and cesium originating from the accident site, albeit at levels considered too small to have effects on human health. Expansion of the testing to weeds, vegetables, and milk from the San Francisco area also detected fission products, again at levels not considered to be harmful.[14]

The disaster at Fukushima was unexpected in the sense that it was caused by a combination of natural events thought highly unlikely by engineers and nuclear safety advisors: an earthquake, which the installation putatively was designed to withstand, followed by a tsunami, which prevented the restoration of electrical power. Within the span of twenty-four-hours one of the most technologically advanced nations on the planet was confronted with a nuclear disaster occurring amidst widespread destruction to the national infrastructure caused by the tsunami.

The resolution of the problems at the Fukushima plant remains uncertain, but the disaster is one that raises important issues, issues with relevance to the operations at DHS.

The question could be asked, why does DHS necessarily need to be involved in screening incoming passengers and cargo for radionuclides associated with a nuclear accident overseas? In the aftermath of the Fukushima disaster, there has been a dearth of information on the amounts of such contaminants present on the clothing and skin of travelers, as well as the exterior and interior areas of aircraft. A CDC staffer indicated that there was no evidence that travelers returning to the United States from Japan were "contaminated with material at a level of concern."[15] If amounts of contaminants on exposed individuals are considered to be negligible, should widespread screening even need to be implemented? The response to this question is, of course, that the psychological impact of the disaster exerts considerable influence on how federal agencies manage their response. While an extended discussion of the psychology of disaster responses and threat assessments/analyses is beyond the scope of this article, it is worth noting that despite assurances from subject matter experts that the amounts of fallout from the Fukushima disaster that reached the mainland United States were minute, there was a surge in purchases of potassium iodide on the part of the American public.[16] Accordingly, Secretary Napolitano's statement regarding "an exercise of caution" served to notify and reassure the public that their government was considering their welfare.

ISSUES SURROUNDING SAFE OPERATION OF NUCLEAR ENERGY FACILITIES

Obviously, a variety of federal agencies, academic institutions, private contractors, and national laboratories have been conducting analyses of weapons of mass destruction (WMD) incidents, with a focus on treatment options for casualties in urban areas. In my experience, there is an extensive body of open-source literature (including white papers and peer-reviewed journal articles) that covers such scenarios. However, the open-source literature concerned with the public health and environmental quality consequences of a nuclear accident is comparatively scant, and tends to consist of reports by investigative journalists, as well as policy and analysis articles by environmental advocacy organizations. This is particularly true of open-source information dealing with nuclear power in non-Western nations. Consequently, I have out of necessity used this material to reference my analysis of the expansion of nuclear power in developing countries.

As of January 2012, the United States leads the world with the largest number of nuclear power plants in operation (104), followed by France (58), Japan (51), and Russia (33). But the economic growth and attendant requirements for increased electrical power experienced by developing nations has made nuclear power an attractive alternative to energy generated from coal, oil, and natural gas. In contrast to the ambivalence about nuclear power experienced by "first world" nations in the aftermath of the Fukushima disaster, China currently operates fifteen reactors for power generation, has twenty-six reactors under construction, and has plans or proposals for another 120 to be constructed over the next several decades. India currently operates twenty reactors, is constructing six, and has plans to build another forty. Neither Thailand nor Indonesia possesses nuclear reactors at present, but each country hopes to build as many as six in the near future.[17]

As opposed to the situation forty or fifty years ago, when contractors in the United States, USSR, Canada, and Western Europe were the only entities capable of erecting nuclear power plants, China has now emerged as a competitive provider of power plant construction. This means that developing countries are no longer required to placate Western governments in order to gain access to nuclear facilities; for example, in the spring of 2010, an agreement was made between China and the Pakistan government to build two 650-megawatt (MW) reactors at the Chashma nuclear complex.[18]

Prior to the Fukushima disaster, the nuclear power industry was adamant that, whether emplaced in first-world or third-world nations, nuclear power remained a safe and ecologically acceptable form of energy production. The World Nuclear Association (formerly the Uranium Institute), an advocacy group formed by nuclear power plant companies, states:

> Today, nuclear power plants have a superb safety record – both for plant workers and the public. In the transport of nuclear material, highly engineered containers – capable of withstanding enormous impact – are the industrial norm. More than 20,000 containers of spent fuel and high-level waste have been shipped safely over a total distance exceeding 30 million kilometres. During the transport of these and other radioactive substances – whether for research, medicine or nuclear – there had never been a harmful radioactive release.
>
> The radiation produced within the core of nuclear reactors is similar to natural radiation but more intense. At nuclear power plants, protective shielding isolates this radiation, allowing millions of people to live in safety nearby. Typically, the radiation people receive comes 90% from nature and 10% from medical exposures. Radiation exposure from nuclear power is negligible.[19]

Not surprisingly, public citizen, environmental, and clean energy activist groups in developing and developed nations disagree with this viewpoint, and argue that a long list of accidents and acts of criminal negligence at nuclear power plants are cause for concern, if not outright trepidation.

An in-depth recitation of such accidents is beyond the scope of this article, but in the aftermath of the Fukushima disaster, developments in Japan are worth mentioning in this context.

Prior to the Fukushima event, Japan relied on fifty-four nuclear power plants to provide 30 percent of its electricity and planned to construct another twelve reactors in the near future.[20] However, serious problems with the safe and conscientious operation of these nuclear facilities were documented. According to the World Nuclear Association:

> In 2002 a scandal erupted over the documentation of equipment inspections at Tepco's reactors, and extended to other plants. While the issues were not safety-related, the industry's reputation was sullied. Inspection of the shrouds and pumps around the core is the responsibility of the company, which in this case had contracted it out. In May 2002, questions emerged about data falsification and the significance of cracks in reactor shrouds (used to direct water flow in BWRs) and whether faults were reported to senior management. By May 2003 Tepco had shut down all its 17 reactors for inspections, and by the end of 2003 only seven had been restarted. Replacement power cost on average over 50% more than the 5.9 yen/kWh (5.5 cents US) nuclear generation cost. Tepco now has all its reactors back on line, with the whole fiasco costing it about JPY 200 billion (US$ 1.9 billion).[21]

Problems stemmed not only from negligent maintenance and inspection, but also from geologic disturbances that occur in Japan. For example, in July 16, 2007, an earthquake measuring 6.8 on the Richter scale damaged the Kashiwasaki-Kariwa nuclear power station facility near Niigata. Despite the plant's location on bedrock (excavated in some places to a depth of forty-five meters, or more than 147 feet) – a construction feature implemented to mitigate any damage from earthquakes – the tremors were of sufficient intensity to sever piping and electrical assemblies within the plant.[22] A transformer associated with the external power supply to the plant caught fire, and two hours elapsed before the fire was extinguished. There was leakage of water into the confines of the plant, and an estimated 90,000 Bq (2.4 μCi) of radioactive water were discharged into the Sea of Japan. Radioactive gasses containing isotopes of iodine, cobalt, and chromium were released from exhaust stack No. 7 in the aftermath of the quake, and while the amount estimated to have been discharged – 400 million Bq (10,810 μCi) – was not considered to be a risk to public health, there were concerns that it represented damage to the fuel assemblies within the reactor.[23]

The damage to the Kashiwasaki-Kariwa plant, which resulted in the suspension of its operation until August 2009, raised questions as to whether even very expensive, dedicated approaches to "earthquake-proofing" a nuclear reactor facility were valid when severe quakes occur. Obviously, the entire concept of Japanese nuclear plant safety in the context of a natural disaster was severely tested by the earthquake and tsunami of March 11, 2011 and their effects on the three operating reactors on the grounds of the Fukushima installation.

The circumstances of the Fukushima disaster, which took place despite preventive measures (such as the presence of backup electrical generators) put in place by Tepco, have important implications for the conscientious operation of reactors, or responses to accidents, in developing countries. These aspects of plant operations and management are complicated by the unavoidable corollary to the generation of nuclear power: the generation of radioactive waste.

The International Atomic Energy Association (IAEA), a nuclear power advocacy organization, estimates that each year approximately 15,500 metric tons of highly radioactive metal waste are generated by the industry worldwide.[24] The prime constituent of this high-level waste is the spent fuel rods removed from the reactor core; these are "hot" in both a radioactive and thermal sense, and must be stored under water to avoid combusting.

[As indicated earlier in this article, the loss of water from the cooling pond atop the Fukushima Daiichi Reactor 4 building in the aftermath of the explosion of March 15 caused major consternation among Tepco personnel][25]

Over a lengthy interval (i.e., ten to twenty years) of so-called "interim storage" the rods in the spent fuel pools lose enough heat and radioactivity to be removed from the water pool and placed in large, shielded containers for "dry" storage.[26]

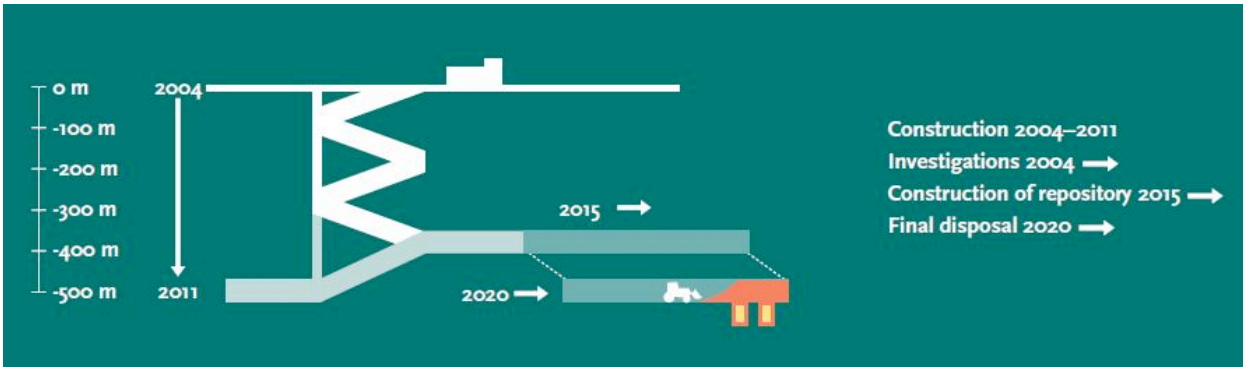
Along with the metal waste, large amounts of less hazardous liquid and solid waste are produced by nuclear reactors. Needless to say, the storage and processing of high- and low-level waste is an expensive and politically charged feature of nuclear plant operation.

To provide an example of the substantial economic and infrastructure resources that must be devoted to the "conscientious" storage and disposal of wastes associated with reactor operation, it is illuminating to look at some examples of what is done in first world nations.

In South Korea, according to the World Nuclear Association, currently all high-level radioactive waste (approximately 9,000 tons of spent fuel) is stored at individual reactor sites, as is intermediate and low level wastes (approximately 60,000 200-liter drums). In order to provide a centralized locale for storage and disposal of these wastes, the South Korean government has commissioned development of an enormous facility near the southeastern city of Gyeongju. The anticipated capacity of the facility is 800,000 drums of intermediate- and low-level radioactive waste. During the spring of 2010, the facility began receiving 200-liter containers of radioactive waste for storage in outdoor areas; in 2012, this waste is expected to be moved to a series of silos located eighty meters (262 feet) underground, for permanent storage.[27]

For long-term storage of its nuclear waste, the Finnish government has chosen to construct a network of tunnels out of the bedrock at the Onkalo facility on Olkiluoto Island (located northwest of Helsinki). The planning for the repository began in 1970, construction is taking place from 2004-2010, waste will be received starting in 2020, and the facility will not be decommissioned until the 2100s. The dimensions of this facility are impressive. The main access tunnel will be 5.5 km (over three miles) long and the lowest level in the facility will be located 520 m (1,706 feet) underground (for comparison, the former North Tower of the World Trade Center in New York City was 110 stories, or 1,368 feet tall) (Figure 2).

Figure 2. Schematic diagram of the Onkalo facility on Olkiluoto Island, Finland, for long-term storage of nuclear waste (from *Onkalo: Underground Rock Characterisation Facility at Olkiluoto, Eurajoki, Finland*).



The storage design calls for waste fuel rods to be packed into large steel and copper canisters (the largest canisters are over five meters, or seventeen feet, in length), which will be placed into cylindrical shafts excavated in the storage areas of the underground tunnels; these shafts would be filled with layers of bentonite clay to cushion the emplaced canisters.[28]

The Onkalo facility, which will cost an estimated 3 billion Euros, is designed to safely store the waste for as long as 100,000 years; it is unclear if information about the site can be maintained in the racial consciousness of *Homo sapiens* (or other sentient creatures that may evolve during such an epoch) for such an extended period of time. Doing so, however, is important, because another Ice Age may well occur in that interval and result in the formation of ice layers two to three km thick over the burial site. The structure of the bedrock of the burial site would be affected by the pressures exerted by such masses of ice, but European authorities are confident that the copper and steel canisters holding the waste fuel rods will withstand such compression.[29]

For economic and political reasons, some governments choose to export their radioactive waste. For example, in 2009 a documentary film-maker named Eric Guéret released a film (English title *Waste: The Nuclear Nightmare*) showing that the Électricité de France company was obliged to ship, by rail, some 108 tons of uranium waste from its nuclear plants at La Hague to a restricted storage facility in Seversk, a town in Siberia. Since the French government permits the uranium to be classified as a "recycled" product, rather than a hazardous waste, its yearly transport is not subjected to regulations imposed on waste shipments *per se*. Such transport is a source of some degree of consternation to communities lying alongside the rail route. But the French are not alone in seeking to export their nuclear wastes out-of-country; from 1996 to 2001, German plants exported some 1,500 tons of waste every year to the Seversk facility. Expansions of this movement of radioactive waste that would ensue from patronage by developing countries would arguably increase the risk of an accidental release of material during the transport process.[30]

It is unclear if less-developed countries have given adequate thought to the disposition of high-level waste that is, and will be, generated by their own nuclear plant operations. It is likely that countries like Pakistan, Jordan, and Armenia will store spent fuel generated at newly constructed reactors on-site, until it achieves temperature and radiation levels amenable to removal to off-site storage. It may be that developing nations will arrange to have their waste transported by rail overland to the Seversk site, much as France and Germany have done.

Alternatively, less developed countries may contract to have their waste interred in sites like Onkalo. But is seems unlikely – at least in light of present-day economics – that developing countries would have the financial resources to construct their own equivalent of the Onkalo or Gyeongju repository. In view of the difficulties encountered with the loss of coolant to the spent fuel pools at the Fukushima reactors, measures to deal with disruptions to on-site storage of nuclear waste will be another costly, but critical, component of disaster response planning for nuclear plants operating in developing nations.

CONSEQUENCES OF A NUCLEAR ACCIDENT IN A DEVELOPING NATION

Are we to expect that developing nations are fully capable of operating their own burgeoning supply of nuclear power plants with an attention to safety that approaches that of first world nations? This is a troubling question, yet a question that, in the aftermath of the Fukushima accident, deserves more attention from scholars in the field of international relations and analysts in academe and government, who have tended to focus on issues relating to nuclear proliferation, rogue states, and terrorism, as opposed to the expansion of nuclear power.

I would argue that social and cultural attitudes that promote malfeasance and corruption in developing nations render these nations more likely to experience a disaster due to negligent operation of a nuclear power facility. For example, while Denmark has a Corruption Perception Index (CPI) score of 9.3, ranking first in the world for honest and forthright commercial exchange, China has a CPI score of 3.6, ranking it seventy-second in the world; India has a CPI score of 3.4, ranking it eighty-fifth in the world; Pakistan has a 2.5 (134th), and Bangladesh a 2.1 (147th).[31]

Such rankings do not, in my opinion, bode well for the absence of major nuclear accidents in developing nations. In this regard, it is illuminating to examine the current situation of India's nuclear facilities with regard to safe and conscientious operation.

OVERSIGHT AND SAFETY: THE CASE OF INDIA

Open source information on nuclear safety, nuclear accidents, and preventive measures in India is not plentiful. According to an October 2009 article in the *Asia Times* online, "data on the [nuclear energy] sector are closely guarded by the nuclear establishment, which functions under the purview of the Department of Atomic Energy (DAE)."[32]

However, some material on the topic is available from the South Asian news media. One of the more high profile accidents in an Indian nuclear facility took place in November 2009, when fifty-five employees at the Kaiga plant ingested small amounts of radiation by drinking water from a cooler that had been (perhaps deliberately) contaminated with tritium. The ingestion of the isotope was discovered through routine monitoring of the urine of employees.[33]

Another accident that received media coverage took place in December 2009 at the Bhabha Atomic Research Centre (BARC), India's main site for nuclear weapons development, when a fire in a photochemistry laboratory killed two students.[34] It could be argued that the accident, however unfortunate, was not caused by acts of negligence on the part of the operation of the nuclear reactors at BARC. However, there is a history of incidents associated with the facility that suggest safety has not received adequate attention. For example, soon after the Dhruva reactor at BARC came online in 1985, it experienced a malfunction involving excessive vibration due to water flow through the fuel assemblies: four metric tons of heavy water overflowed from the reactor core. Operation was suspended until January 1987, and the reactor did not generate its full power until January 1988.[35]

After the resumption of the reactor, safety issues continued to occur. In 1989 a technician was accidentally locked into a shielded room in the reactor building; he was only rescued after he repeatedly shut off the coolant pump to the reactor, which in turn shut down the reactor and drew the attention of the staff. In 1991 the reactor operated for nearly a month with a malfunctioning emergency coolant system. And, according to investigative journalist A. Gopalakrishnan, underground pipes used to transport radioactive fluid waste around the BARC campus have burst, contaminating large tracts of the subsoil. Tanks containing large volumes of liquid waste (in a manner reminiscent of the storage setup that led to the Kyshtym disaster) have been leaking, and not subjected to timely repair or replacement.[36]

It is unclear if nuclear power plants in India have fully cooperated with the citizenry in outlining what is to be done in the event of accident of major magnitude. One grass-roots organization, the People's Movement Against Nuclear Energy, has accused the operators of the Koodankulam nuclear power plant in Tamil Nadu state of neglecting to conduct safety drills, or to share evacuation plans, with residents in the surrounding areas.[37]

There are indications that the Fukushima event has introduced a cautionary note to the expansion of nuclear power in India; in Madban, plans to construct the world's largest nuclear power facility (the Jaitapur Nuclear Power Plant, consisting of six reactors) have provoked calls for a moratorium on its construction by Indian scientists and activists.[38] Whether construction will proceed despite such opposition, and whether it will be conducted with increased attention to safety issues, remains to be seen.

If, as I am positing, a major nuclear accident takes place in a developing nation within the next several decades, what is the potential severity of such an accident, and what type of response will be required of homeland security operations in the United States?

In this context it is sobering to note the findings of an interim report on the Fukushima disaster released in December 2011 by Tepco. Among other findings, the report discloses that Tepco officials had designed the plant to withstand a tsunami wave of twenty feet in height; however, the wave that struck the plant on March 11 was more than forty feet in height. In the immediate aftermath of the earthquake and tsunami the workers made the erroneous assumption that the emergency cooling system for Reactor No. 1 was operating, when in fact it was defunct. The absence of adequate cooling was responsible in part for the explosion within the reactor building the next day. Arrangements to deal with a loss of electrical power were inadequate; in one instance, workers were forced to use car batteries to operate valve assemblies associated with the cooling systems. Tepco had placed an emergency operations center about three miles from the plant, but the operations center was not adequately shielded against the radiation exposure that would have been created by a nuclear disaster; consequently, it was of questionable utility during the Fukushima crisis. Data on the dispersal of radionuclides resulting from the reactor explosion were not forwarded to the government in a timely manner. As a result, on March 12, 8,000 evacuees from the town of Namie, near the Daiichi complex, traveled to the village of Tsushima with the expectation that it was safer than Namie. In fact, the extent of radionuclide contamination at Tsushima exceeded that of Namie.

More revelations will undoubtedly be brought to light in the next six months, but it is apparent that despite their considerable experience in the design, construction, and operation of nuclear power facilities, both Tepco and the Japanese government had so discounted the likelihood of an accident at the Fukushima complex they were unprepared to cope with the totality of events triggered by the March 11 earthquake.[39]

As of December 2011, the cost for dealing with the disaster at the Fukushima Daiichi nuclear power plant is estimated to be $257 billion and to require several decades to complete, by every measure a sizable cost to one of the world's most affluent nations.[40] It is doubtful that equivalent financial resources could be brought to bear by the governments of developing nations on a disaster within their borders.

PROXIMITY TO POPULATION CENTERS: THE CASE OF BANGLADESH

Most of the developing nations using, or contemplating using, nuclear power plants share a problem confronting Japan and its handling of the Fukushima disaster: close proximity of the reactor site to population centers. For example, Bangladesh has contracted with a Russian firm to construct two reactors at the Rooppur site in Pabna District.[41] The Rooppur site is only about 180 km (112 miles) from Dhaka; a reactor explosion that distributes radionuclides (Table 2) over an area equivalent to only half that of the Kyshtym disaster of 1957 (for example) would hypothetically contaminate the largest population center in Bangladesh.[42] It is unclear if the Bangladesh government would be able to execute an evacuation of large numbers of people from a heavily populated area, such as that surrounding the Rooppur site, should an accident take place. The alternative to evacuation, having people remain within contaminated zones, may be the only recourse available to the Bangladesh government.

Such a scenario would constitute a humanitarian challenge of unprecedented scope, since it is doubtful the government would be able to supply the affected multitudes with necessary quantities of uncontaminated drinking water and food for what may be months (if not years) of post-accident habitation. Indeed, it is likely that millions of Bangladeshis would unwillingly be forced to inhale radionuclides in their air, as well as ingesting them from contaminated fresh water, crops, and food animals. Providing adequate medical care to such a large number of exposed persons would be an extremely difficult endeavor for the Bangladesh government, thus, morbidity and mortality due to exposure to beta- and gamma-radiation emissions presumably would be very high.

Particularly worrisome with regard to potential casualties is the prevalence of malnutrition among Bangladeshis, particularly women and children; in a 1984-2005 survey of admissions to a hospital in Dhaka, 47 percent of children were underweight, 30 percent were stunted, and 22 percent were "wasting" (i.e., losing weight).[43] Such individuals, with their immune systems already handicapped by malnutrition, will face additional immunosuppression from the effects of ionizing radiation. This will exacerbate their vulnerability to infectious diseases, which may be a major threat to public health if large numbers of exposed persons are gathered into refugee camps. The historical experiences of Bangladesh in regard to cyclone-associated mortality are of import in this regard; for the 1970 and 1991 cyclones, the estimated mortality figures were 300,000 and 138,000 deaths, respectively. A considerable proportion of this mortality was assumed to be derived from causes not directly associated with drowning, or severe physical injuries, associated with the cyclone *per se*, but rather from disease spreading in the storm's aftermath.[44] In the event of a catastrophic nuclear accident in Bangladesh, mortality statistics of this magnitude are depressingly likely.

Even if casualties due to exposure to radionuclides would be small, the economic consequences of a nuclear disaster in a developing nation such as Bangladesh would be significant. The lesson from the Chernobyl accident is sobering: milk throughout much of northern Europe and the British isles was discarded due to contamination with ^{131}I and, to a lesser extent, ^{90}Sr. When testing indicated that many livestock had accumulated significant quantities of radionuclides in their tissues, restrictions were placed on the slaughter of animals for use in the human food chain. With regard to international trade, many nations imposed bans and restrictions on a variety of agricultural products; for example, Germany banned the importation of Italian vegetables, while Italy in turn banned imports from Austria, the Eastern Bloc, Scandinavia and Switzerland. Outside the European Economic Community, Sri Lanka destroyed imports from Europe, and Jordan refused imports of goods from some countries for up to three months following the accident.[45]

Early on in the Fukushima disaster many countries restricted food imports from Japan, particularly seafood.[46] In July 2011, the disclosure that nearly 1,500 beef cattle had consumed rice straw from the Fukushima area; that beef from these animals harbored concentrations of radioactive cesium well in excess of government thresholds; and that some citizens had unwittingly consumed this beef, has had a deleterious impact on the Japanese beef industry.[47]

For developing nations, particularly those that rely on agricultural exports as a major source of revenue, loss of such income for an indefinite period of time may provoke a collapse of the national economy. Such economic travails may exacerbate the increased movement of refugees or migrants from the affected country.

SCOPE OF HOMELAND SECURITY OPERATIONS IN THE EVENT OF A NUCLEAR DISASTER OVERSEAS

The Fukushima disaster has demonstrated the nature of DHS operations in the event of a nuclear disaster overseas (albeit one taking place in a first-world nation with considerable economic and technologic resources available to combat the disaster).

What radioactive contaminants are associated with the Fukushima disaster and being monitored by CBP? As is shown in Table 2, among the list of possible radionuclides ejected from a reactor explosion are a number with comparatively short half-lives, such as ^{131}I, ^{133}Xe and ^{140}Ba. Other radionuclides possess lengthy (i.e., hundreds of years) half-lives, including ^{90}Sr, ^{137}Cs, and isotopes of plutonium. Some radionuclides are beta-emitters, such as ^{90}Sr, while others are gamma-emitters, such as ^{137}Cs. In the initial aftermath of the disaster, attention was focused on the dispersal of gamma emitters such as ^{131}I and isotopes of cesium, although soil sampling from March 2011 revealed, in addition to these species, the presence of (short-lived) isotopes of tellurium, barium, and lanthanum.[48]

Radionuclide (decay)	Half-Life (in days)
krypton-85 (β)	3,950
xenon-133 (β, γ)	5.3
iodine-131 (β)	8
cesium-134 (β)	750
cesium-137 (β)	11,000
strontium-90 (β)	10,400
ruthenium-106 (β)	0
barium-140 (β)	13
cerium-144 (β)	2.8
plutonium-238 (α)	32,500
plutonium-239 (α)	9×10^6
curium-242 (α)	163

Table 2. Selected radionuclides that may be ejected from a reactor core in the event of an explosion or fire.[49]

The main agency within DHS playing a role in the response to the Fukushima disaster is Customs and Border Patrol (CBP). Indications are that in the aftermath of the Fukushima incident, DHS technologies such as radiation portal monitors (RPM) and Hand-Held Radioisotope Identification Devices (HHRIID) are proving useful in a new role in screening incoming cargo for radionuclides associated with the Fukushima incident.[50] As mentioned at the start of this article, CBP was conducting screening of incoming cargo and persons from the affected area for the presence of radioactive contamination; judging by open-source information, CBP management of this process led to some delays in the transport of goods received at shipping ports, but overall, there did not appear to be a deleterious effect on cargo movement.[51] This is despite the fact that some CBP operations were being conducted at some distance from port facilities; according to a March 25, 2011 article in *The Journal of Commerce*, the Coast Guard and CBP were tracking vessels transiting the fifty-mile fallout zone around the Fukushima site en route to the United States, with radiation screening of ship contents being conducted at sea if warranted.[52]

CBP was also assisting the FDA with the logistics of screening incoming food and pharmaceutical products from Japan. As of January 12, 2012, the FDA had tested 1,923 food samples, only one of which had detectable levels of ^{137}Cs / ^{134}Cs.[53] All testing evidently has been performed at the Winchester Engineering and Analytical Center (WEAC) in Winchester, MA, with the six laboratories participating in the Food Emergency Response Network (FERN) capable of buttressing this capacity if needed.[54]

To summarize, as best can be inferred in January 2012, DHS operations (both individually and in conjunction with other federal agencies) to screen incoming cargo and persons from Japan for radionuclides worked successfully. DHS deserves commendation for rapidly responding to a scenario that deviated significantly from those its operations were originally devised to address (i.e., nuclear terrorism).

One aspect of the Fukushima incident has not necessarily been very informative for planning for DHS responses to a nuclear disaster in a developing country: namely, the advent of large numbers of refugees and emigrants seeking admission to the United States. While the days immediately after the disaster saw a sudden exodus of foreigners from Japan, comparatively few of these individuals had received significant exposure to radionuclides.[55] It seems reasonable to propose that, in the event of a nuclear disaster in a nation adjoining the continental United States (e.g., Mexico or Canada), large numbers of individuals will be exposed to fallout and a larger proportion of these individuals may seek to enter the United States. Not all of these individuals will represent foreign nationals or refugees; some may be US citizens and dependents. While it appears that the screening of persons entering the United States in the aftermath of the Fukushima disaster was carried out with reasonable efficiency, whether such screening procedures would be practicable in the event of a catastrophe in a nation neighboring the United States, and a concomitant influx of larger numbers of affected individuals, is unclear. This may be one of the more challenging duties that will await CBP in the event of a nuclear disaster in a country adjacent to the United States.

For an example with relevance to such a scenario, a modeling study by Canadian investigators looked at high-throughput screening of as many as 20,000 exposed individuals, who walked past a portal-based gamma detector. The extent of contamination was hypothesized to range from forty to 900 MBq for ^{137}Cs. For comparative purposes, the screening of 300 people involved in the Goiania (Brazil) contamination event recorded a maximum ^{137}Cs contamination level of forty-two MBq.[56] When screened in groups of five, individuals contaminated with seven MBq of ^{137}Cs could be detected, while an exposure corresponding to 1.2 MBq of ^{137}Cs was undetectable. The investigators noted that the speed of the screening process was obviously dependent on factors such as the cooperation of the exposed persons, as well as the physical mobility of the individuals, their familiarity with the language used by the screening staff, and the efficiency with which groups of people could be organized in a large area as part of the pre-screening procedure. The model predicted that screening of 20,000 people under a sixteen-hour-per-day regimen required twelve to forty-three days, depending on the size of the screening groups. If multiple monitors were deployed, the screening time could be reduced to approximately three days (Table 3, below).[57]

Screening group size	**Screening time (in days)**
1	42.7
2	27.1
3	21.9
5	17.7
10	14.6
21	12.9
42	12.2
84	11.8

Table 3. Estimated time required to screen 20,000 persons exposed to the equivalent of 7 MBq ^{137}Cs using different screening group sizes.[58]

These types of modeling studies can be useful in estimating the radiation monitoring capacity that may be required of DHS in order to screen incoming persons in the aftermath of a nuclear accident resulting in a greater exposed population than the Fukushima incident. As well, dealing with a population of incoming persons that may not be fluent in English, and may be suffering from a variety of physical and emotional ailments, will present special challenges to the staff of such screening operations. In this context, some experts advocate for additional research and development of methodologies for effectively communicating monitoring procedures and results to screened individuals.[59]

While the knowledge gained from operations associated with the Fukushima incident will be useful, more information regarding the logistical challenges associated with setting up and operating high-throughput screening operations at major airports or other facilities will be needed to enhance CBP capabilities in this area.

How long will DHS need to plan to provide screening for imported goods, refugees, and detainees? The question is difficult to answer and depends on a number of factors, chief of which is the ability of the affected nation to implement measures to restrict the export of potentially contaminated goods and materials, as well as to provide medical care to exposed persons. If the Chernobyl disaster is any guide, there is a disturbing likelihood that as time goes on, materials containing radionuclides will be transported from the accident zone into other areas, as clandestine movement of materials from contaminated sites will be hard to police by a government strained with the task of addressing the massive social and economic problems ensuing from the event.[60] Accordingly, DHS may need to implement screening measures for several years in the aftermath of a nuclear accident in a developing country, as economic and political problems stemming from an inability to deal with the disaster may continuously generate a stream of refugees seeking admission to the United States.

CONCLUSION

In contrast to historical nuclear disasters such as the Kyshtym explosion and the Windscale fire, both of which took place in 1957, the Fukushima nuclear disaster was not caused by human error *per se*; rather, it was triggered by two successive geologic disturbances for which the facility was unprepared: an earthquake and a tsunami.[61] It could be argued that this was a rare coincidence and unlikely to be the cause of failure at other nuclear facilities. However, in this article I have posited that in the case of nuclear power plants operating, or planned to operate, in developing nations, a number of factors other than unprecedented geologic disturbances may contribute to increased risk for a catastrophic incident.

In the case of Iran, for example, the use of outdated equipment may be the issue; in February 2011, reports surfaced in the news media that the forthcoming startup of Iran's nuclear reactor at Bushehr had been indefinitely delayed. Rosatom, the Russian firm supervising the reactor's construction, announced that one of the four cooling pumps had been damaged and needed to be replaced; this meant that the fuel had to be removed from the reactor core, a lengthy and expensive process. The pumps date from the 1970s, when a West German firm had contracted to build the reactor, but withdrew following the 1979 revolution. The incorporation of these obsolete pumps into the Bushehr facility is not only difficult from an engineering point of view, but raises questions as to their effectiveness once the reactor becomes operational.[62]

The DHS, and CBP in particular, has demonstrated the ability to respond in an effective manner to the Fukushima disaster. This bodes well for DHS operations in the event of a nuclear catastrophe in Iran, Bangladesh, or another developing nation that (unlike Japan) will lack the economic and political structures to deal with such an event. It is reasonable to expect that in such a scenario DHS will need to expand its capabilities to screen incoming persons and goods for contamination. As this article has pointed out, further investigations and analyses are needed in these areas to ensure that the agency is well positioned to deal with the unusual nature of such a crisis.

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